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THE SPECTRA OF SOME SPIRAL NEBULÆ AND GLOBULAR STAR CLUSTERS.[1]

This investigation was undertaken to test the correctness of the statement frequently found in astronomical literature that the spectra of the spiral nebulæ are continuous, and to increase our knowledge of these spectra in any manner possible. A few globular star clusters were added to the program for reasons given below.

There are but two published observations, as far as known, which cast any doubt on the continuous character of the spectra of spiral nebulæ—one by SCHEINER[2] and the other by HUGGINS,[3] both of whom worked on the *Andromeda* nebula. Each of these observers obtained a spectrogram showing absorption lines: the former, lines corresponding to G (λ 4308) and H (λ 3969) of the solar spectrum; the latter, the G, H, and K (λ 3934) lines, with some others not named. The spectrogram by SCHEINER was probably faint and there may be some doubt as to its interpretation, for the late Director VOGEL, who presumably saw the plate, when revising NEWCOMB-ENGLEMANN'S *Populäre Astronomie* several years later, said on page 577: "Selbst über das Spektrum des bekannten Andromedanebels ist nichts weiter bekannt, als dass er nicht das sonst bei Nebeln gewöhnlich vorkommende Gasspectrum zeigt." HUGGINS does not seem to think his plate entirely free from suspicion, for he says:[4] "The photograph . . . we had put aside . . . as probably vitiated, in some unknown way, by the coming in of direct solar light, or of moonlight." The basis for this suspicion is due to the fact that an overexposed solar spectrum was imprinted on the same plate for comparison. HUGGINS also observed visually some bright lines in the spectrum of this nebula.

These two photographic observations agree in showing absorption lines present in this nebular spectrum; but, judging from the circumstances as noted, the evidence can hardly be called conclusive.

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[1] Abstract of *Lick Observatory Bulletin*, No. 149.

[2] *Astronomische Nachrichten*, **148**, 325, 1899.

[3] *Atlas of Representative Stellar Spectra*, p. 119, 1899.

[4] *Atlas of Representative Stellar Spectra*, p. 126.

The telescope used in the present investigation was the Crossley reflector.[5] Some preliminary work by the writer, in the summer of 1907, with this telescope and a small quartz spectrograph, on the *Andromeda* nebula promised interesting results. Accordingly a special spectrograph[6] was designed for efficiency in observing such faint objects, using optical and other materials in part already on hand.

The extremely feeble intensity of the light of the spiral nebulæ, even the very brightest, is hard to realize. A comparison of stellar spectrograms taken with the instruments used in this investigation and those made with the Mills spectrograph attached to the 36-inch refractor shows that the latter requires from twenty to thirty times as long an exposure as the former to obtain spectrograms of the same density, using the same slit-width in both cases.[7] Assuming the ratio of the exposures as 1:25, and using a slit-width of 0.08^{mm} and Lumière Σ plates, it would take an exposure of 450 hours with the Mills spectrograph to obtain a satisfactory plate of the brightest part of the *Andromeda* nebula, which is one of the brightest of the spirals. This statement is based on plate 45, which is of about the proper density. It is further based on the favorable assumption that for a spectrum of given intensity the exposure time varies inversely as the intensity of the light falling on the plate. As is well known, this is not the case, so that a 500-hour exposure would probably be nearer the truth. Under similar conditions a plate of *Arcturus,* which is of the same spectral type, could be secured with the Mills spectrograph in less than two minutes.

The results of this preliminary investigation may be summed up in the statement: No spiral nebula investigated has a truly continuous spectrum. While this may be a step in advance, nevertheless it is wholly inadequate to answer the question as to the real nature of these interesting objects which the work of KEELER brought so prominently before the astronomical world. Their spectra vary from those having principally bright lines such as are found in the gaseous nebulæ to those containing only absorption lines of the solar type.

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[5] For a description of this telescope with its present mounting, see *Lick Observatory Bulletin,* **3,** 124, 1905.

[6] For a description of this spectrograph, an account of the methods of observing, and of the details of the results obtained, the reader is referred to the original paper.

[7] The purity, of course, would be vastly different owing both to the difference in focal lengths of the respective collimator lenses and the great difference in dispersion.

In trying to interpret these results it must be remembered that the spectrograms obtained record only the spectra of the denser central portions of the nebulæ. In the case of the *Andromeda* nebula this amounts to five minutes of arc. Then, too, the very low dispersion of the spectrograph used undoubtedly masks much that is of fundamental importance. Whether the spiral arms will give the same spectrum as the central portion is a question which will be difficult to answer with present appliances.

Careful consideration has been given to various hypotheses to account for the character of the spectra photographed. Only one hypothesis seems at all tenable, and serious objections can be advanced against this one. It may be termed the "star-cluster" theory, reached by the following considerations.

The only known sources of continuous spectra are luminous solids, liquids, very dense gases, or possibly masses of gas of great thickness. To produce bright lines or bands we require gases or vapors rendered luminous by heat, electric discharges or chemical change, or substances made to fluoresce by energy supplied by some external agency. For absorption lines or bands to be present the necessary condition is an absorbing medium, usually of a gaseous nature, between a source of continuous radiation and the observer. These are, for the most part, well established experimental facts.

The primary or fundamental part of the spectra of the spiral nebulæ is a continuous background. This is interrupted by absorption lines, and superimposed upon it in some cases are bright lines or bands. The matter producing the lines, bright or dark, must be assumed to lie between the source of continuous radiation and the observer. Hence we conclude this source to be surrounded by a gaseous envelope, of physical condition varying in the different nebulæ and corresponding to the various spectra obtained. The only celestial bodies of this type with which we are acquainted are the stars.

The hypothesis that the central portion of a nebula like the famous one in *Andromeda* is a single star may be rejected at once unless we wish to modify greatly the commonly accepted ideas as to what constitutes a star. Assuming, however, an unresolved star cluster consisting of stars mainly of solar type we would seem to have a sufficient explanation of the spectrograms of the *Andromeda* nebula. But the question arises: Is it reasonable to assume that in a condensed cluster we should have stars of one spectral type strongly predominating?

In seeking an answer to this question I have found but two references to observations of the spectra of known dense star clusters. These are not sufficiently definite to settle the matter. HUGGINS,[8] in reporting an observation on the great cluster in *Hercules,* says: "Spectrum of central blaze continuous. Spectrum ends abruptly in the orange. The light of the brighter part is not uniform; probably it is crossed by bright lines or lines of absorption." VOGEL[9] likewise observed this cluster and writes as follows: "Der bekannte Sternhaufen im *Hercules* zeigte ein sehr schwaches continuirliches Spectrum, welches sich von ca. 620 bis 450 Milliontel Millimeter verfolgen liess. In demselben waren einige dunkle Streifen zu erkennen, konnten aber wegen zu grosser Lichtschwäche nicht gemessen werden."

It was accordingly necessary to investigate some known star clusters. From the Crossley negatives three dense clusters were selected for trial—N. G. C. 6205, 7078, and 7089. The first, the famous cluster in *Hercules,* gave evidence of containing stars of different spectral types, while the other two gave F-type spectra only. Photographs show clusters such as these to be made up of two groups of stars,[10] the one of magnitudes 11 to 13 and the other of about magnitude 16. The brighter group was probably the only one giving the spectrograms. If we could view such a cluster from a distance so great that it could not be resolved into its component stars there is no question but that it would continue to give such spectrograms as have been described. We thus have the question as to whether clusters can be found in which stars of one spectral type predominate answered in the affirmative.

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[8] *Philosophical Transactions,* **156,** 389, 1866.

[9] *Astronomische Nachrichten,* **78,** 245, 1871.

[10] *Lick Observatory Bulletin,* **3,** 49, 1904, and *Astrophysical Journal,* **20,** 354, 1904.

The "star cluster" interpretation of the results obtained stands or falls by the question of parallax. It does not seem reasonable to assume stars that should be many times smaller than the Sun. We also require the cluster to be at such a distance that it cannot be resolved. Now the only determination of the parallax of a spiral nebula that the writer has been able to find is that of the *Andromeda* nebula by BOHLIN.[11] He finds this to be $0''.17$. His result rests on two separate determinations, each of which gave positive values for the parallax both in α and δ. The result is therefore entitled to some confidence. If, now, the parallax of the *Andromeda* nebula is of this order of magnitude, the "star-cluster" theory, at least for this particular object, is not very satisfactory. For, assuming this parallax; a surface brilliancy of the component stars equal to that of the Sun; and a ratio of brightness of the central portion of this nebula to that of the Moon of 1/180,000 (derived from Crossley negatives): a simple computation shows that if the stars are so closely packed as to be irresolvable their dimensions are of the order of the asteroids; while if assumed only as large as *Jupiter* they would appear some seconds of arc apart. This is not found to be the case. The "star-cluster" theory, however, seems to be the only one that can at all adequately explain the spectrum obtained, and another determination of the parallax, preferably by another observer with a different instrument, would be of great interest.

The theory as given above is not a new one, but with the exception of the work of SCHEINER and HUGGINS on the *Andromeda* nebula there were no facts, so far as the writer has been able to find, to support it. Even now the material is very meager and more questions have been raised than answered. We still know nothing concerning the spectra of the spiral arms and little or no light is shed on the fundamental questions of the origin of the spiral nebulæ, their relations among themselves, and to other stellar objects. These questions must be left for the future.[1]

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[11] *Astr. Iaktt. o. Unders. A Stockholms Obs.*, **8**, No. 4, 66, 1907.

E. A. Fath.

Mt. Hamilton, December, 1908.

Note on the Classification of Double Stars.

Lick Observatory Bulletin, Number 158, contains another list of one hundred new double stars discovered and measured with the 36-inch telescope. This list brings the total number of my published discoveries to two thousand. Arranging these stars according to their angular separation, we have the following table:—

Distance	No. of Pairs	Percentage
0″.25 or less	182	9.10
0 .26 to 0″.50	444	22.20
0 .51 to 1 .00	400	20.00
1 .01 to 2 .00	450	22.50
2 .01 to 5 .00	511	25.55
5 .01 or greater	13	0.65
	2000	100.00

From this table it appears that more than one half (51.3%) of the stars listed belong to Struve's Class I (distance 1″ or less), and that nearly three fourths (73.8%) fall within the 2″ limit. The thirteen pairs which exceed the limit 5″.0 have components whose difference in brightness averages 5.7 magnitudes. In only three cases does the angular separation exceed 5″.2. Though the program of my survey contemplates the systematic examination of the stars only to the magnitude 9.0, inclusive, it is inevitable that fainter stars should from time to time be brought into the field of the telescope. In this way many fainter pairs have been discovered, but, in general, only the very close ones have been listed. In all, I estimate that considerably less than 10 per cent of the pairs published have components whose combined brightness falls below 9.0 B. D. magnitude.

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[1] The publication of the above paper was unavoidably delayed. Since it was written Professor Barnard has published the results of a photographic investigation of the *Hercules* cluster in the *Astrophysical Journal,* **29**, 72, 1909. He finds that this cluster is composed of stars of different spectral types. The spectrographic results obtained by the writer are in agreement with this.

E. A. Fath.

March, 1909.